THE GROWTH AND SIZE DISTRIBUTION OF CURRENT YEAR CLASS LOLIGO PEALEI [1]

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Loligo pealei (Lesueur, 1821) is the common squid between Cape Cod and Cape Hatteras (Verrill, 1882). It is abundant inshore during the warmer part of the year and is concentrated near the Continental Shelf break in the winter time (Summers, 1967). In spite of its ubiquity, its apparent importance in pelagic food chains and its significance as a source of "squid giant axons," the life history of *L. pealei* has not been fully described.

Verrill (1882) and Haefner (1964) both estimated the growth rate of this species by equating different year classes with size-frequency modes. By this method, Verrill suggested that the largest individuals were three or four years old and Haefner demonstrated two distinct year classes. Their analyses were subjective when the size classes overlapped each other and contained the assumption that *L. pealei* grows at a continuous, if not uniform, rate through its life span.

Verrill's report was based upon a synthesis of preserved specimens and was presented as a description of the growth rate of *L. pealei* off the "southern coast of New England." His tabulated data included measurements of approximately 3378 individuals, more than 2600 of which were collected in Vineyard Sound, south of the Cape Cod peninsula. Haefner cited morphometric data on 1165 individuals taken in Delaware Bay during the summer of 1958. His size-frequency information was pooled over the collecting period and consequently cannot be used to demonstrate short-term growth. Neither study fully accounted for the sampling bias of the collecting gear.

The abundance of *L. pealei* in Vineyard Sound during the warmer part of the year is known from Verrill's collections and from the work of Sumner, Osburn and Cole (1913). The latter dredged specimens throughout the waters surrounding Woods Hole, Massachusetts, and indicated a concentration in the southwestern part of Vineyard Sound. During the past five summers, the fishing vessel CAP'N BILL IV, under charter to the Marine Biological Laboratory, has trawled for this squid on 181 different occasions in the southwestern part of Vineyard Sound.

The present paper attempts to more precisely describe the early growth and size distribution of *L. pealei* in Vineyard Sound. The study was facilitated by dealing primarily with the numerous, rapidly growing current year class (individuals less than one year old) and by the fact that Vineyard Sound is near the northern range limit of this species where the breeding season is relatively

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FIGURE 1. A contour map of Vineyard Sound. Menemsha Bight is located at 41° 22′ N, 70° 48′ W. The mean water depths are given in meters; the sampling region is shown by a heavy 20-m. contour line in Menemsha Bight.

short. Sampling was restricted to one location and procedures were consistent throughout the study in order to determine seasonal changes. This work was undertaken as a part of a continuing study of the ecology of *L. pealei.*

Methods

The growth rate and longevity of *L. pealei* could not be determined in the laboratory because this animal can not be reared in captivity. A program of tagging and recapture of squid in the field did not seem practical short of a large scale operation. The remaining option was to repeatedly determine the size-frequency of a natural population and infer growth from the changes between sampling dates. This method was employed knowing that it introduced the least experimental bias in growth estimates and required the greatest care in sampling from a single population.

The site chosen for this study was Menemsha Bight (41° 22′ N, 70° 48′ W), a shallow open embayment at the southern extreme of Vineyard Sound, west of Martha's Vineyard Island. As illustrated in Figure 1, Menemsha Bight is partially protected from the open waters of the Atlantic Ocean by the Gay Head promontory. The Bight has an unobstructed, gently sloping sandy bottom and normally does not have tidal currents in excess of 3 km./hr. There is little temperature stratification in Vineyard Sound due to significant water movement and the annual surface temperature cycle ranges from 0 to 22° C. in February and August, respectively. Sea-water salinities remain consistently at 31 to 32‰ through the year. The sampling region is shown by a heavy 20-m. contour line in Figure 1. This region was accessible for otter trawling for a linear distance of approximately 5 km.

Squid were taken with a #35 otter trawl towed by the stern rigged, 65-foot (20-m.) research vessel A. E. VERRILL (named for the author cited above). Except for the addition of a 1.25-inch mesh (3.2-cm.) stretched measure nylon liner in the cod end, this was a typical New England commercial groundfish net. The trawl doors weighed 500 lb. (225 kg.) apiece and each was separated from the net by 12 fathoms (22 m.) of groundlines and legs. The headrope and footrope measured 52 and 72 feet (16 and 22 m.), respectively and the forward part of the net was made of 42-thread nylon twine with 5-inch mesh (13-cm.) stretched measure in the wing and square sections and 4½-inch mesh (11-cm.) stretched measure in the belly and cod end. The headrope had 12 8-inch (20-cm.) aluminum floats spaced along its length and the foot rope was protected by 4- and 6-inch (10- and 15-cm.) rubber rollers.

All of the samples were taken near midday (earliest 1031 hours, latest 1422 hours) and the tows averaged 50 minutes in duration. The towing speed was 6.5 km./hr. except on the first two sampling dates when a slightly slower speed was employed. The contents of the net were dumped into large tubs on the deck and sorted immediately. The entire squid catch, or a representative sample of several hundred individuals, was measured and sexed as soon as possible after capture. No preserved specimens were included in the results.

The dorsal mantle length was recorded for every individual in the sample; squid less than 5 cm. were measured to the nearest whole millimeter, larger squid were measured to the nearest whole centimeter. The ventral mantle wall was slit open and the sex was recorded for all but the smallest, immature individuals. Males were considered mature when spermatophores were present; this was always accompanied by a thickening and white coloration of the vas deferens. Females were considered mature when the ovary was expanded and loose eggs were found in the oviduct.

Results

A total of 1619 individuals were measured from samples collected in Menemsha Bight on seven consecutive dates ranging from August 18 to November 16, 1967. The numbers of squid caught on November 2, 16 and 22 were approximately 1000, 5 and 0, respectively, and none were taken through March of the following year. *L. pealei* was the only species of cephalopod taken. Many species of fish were caught, some in abundances of several hundred pounds per tow.

It is apparent from the size-frequency data for squid taken on the first sampling dates that current year class *L. pealei* were represented by a few small individuals mixed in with the larger size classes. This class grew and became more dispersed in later samples and eventually merged with the larger classes in late September. The current year class was initially characterized by a narrow size range and illustrated a marked skewness toward the larger sizes. Examination of the various size-frequencies showed that the current year class and the older classes were adequately approximated by lognormal size distributions.[2] Thus, it was possible to more rigorously separate the size classes on lognormal probability paper using the method described by Cassie (1954, 1962). Appropriate age categories could be assigned to these size classes by contrasting the collections on different dates.

The best fit size distributions for six sampling dates are shown in a lognormal probability presentation in Figure 2. Age classes are indicated by brackets to the right of the best fit lines in this figure. The amount of class overlap can be seen in Figure 2 by the horizontal coincidence of different age classes on a single sampling date. It should be noted that Cassie's method of size class separation is based upon size distributions and is little affected by exceptional individuals or the location of the modal size. The latter generally occur at a point below the cumulative 50% in Figure 2.

The current year class made up an increasing proportion of the samples during the time covered by this study. The percentage of current year class individuals in the measured samples is shown for various dates in Figure 3. The dashed line refers to a sizeable catch of *L. pealei* (308 individuals) taken with a 16-foot (5-m.) shrimp trawl under the same conditions give above. There were no current year class squid in this sample and the one plus year class had 5th, 50th and 95th percentile lognormal fit mantle lengths (equivalent to the ends and middle of the lines shown in Figure 2) of 6.8, 9.3 and 12.7 cm., respectively. The dotted line on November 16 indicates the last date of squid capture for the 1967 season.

Figure 4 shows a growth scheme for the current year class *L. pealei* based upon the best fit lognormal size distributions illustrated in Figure 2. The bars

[2] A lognormal size distribution is one in which the logarithm of the variate (in this case, mantle length) is normally distributed. Size distributions in this report are all positively skewed, implying that the modal size lies closer to the lower range size than the upper range size. A positively skewed lognormal distribution restricts the variate to values greater than zero.

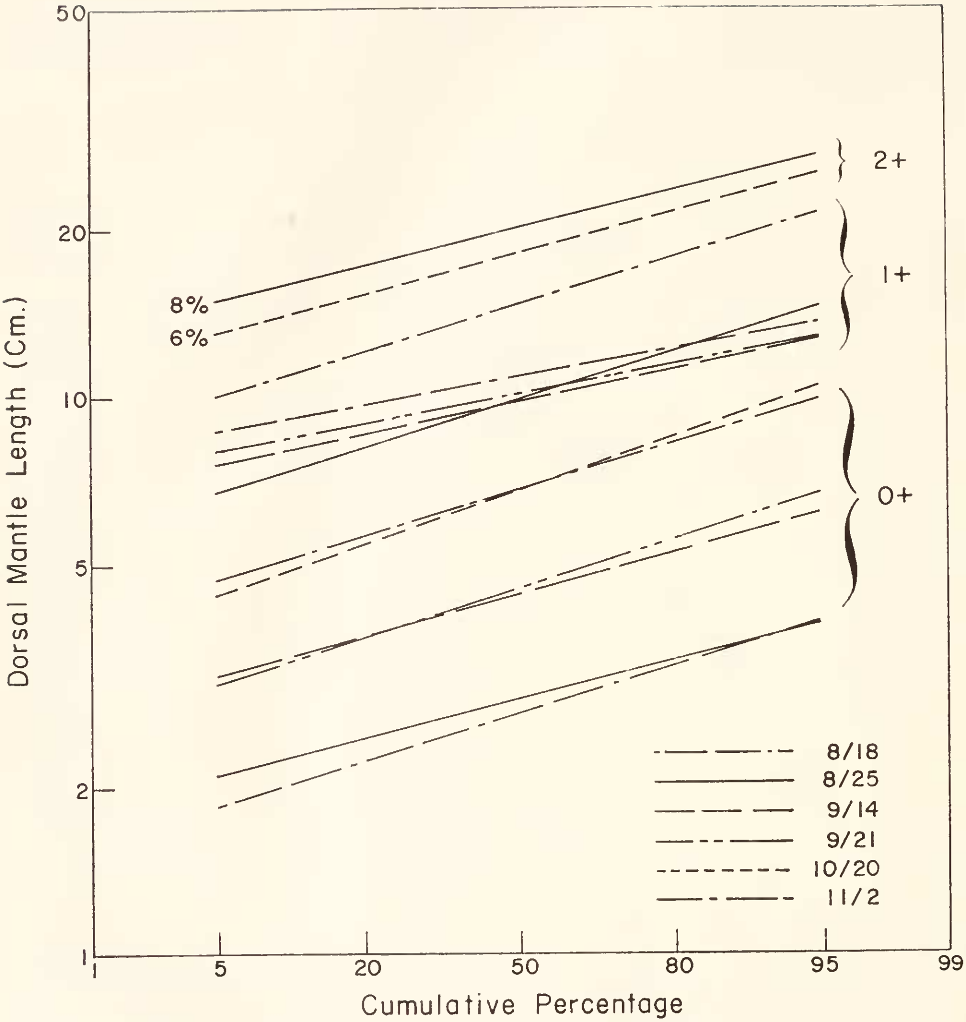

FIGURE 2. Best fit lognormal size-frequencies for different age classes of *L. pealei* resulting from six collections. This is a lognormal probability presentation of the data. Age classes in years are shown by brackets to the right of the fit lines. Sampling dates are indicated by the line codes given in the figure legend. The percentage occurrence of two plus year class individuals in the samples is shown by numerals to the left of the fit lines.

extend from the 5th to the 95th percentile sizes and the dots represent the median, or 50th percentile size. Linear regression lines are given each of these percentages and drawn out from the hatching size (2 mm. mantle length) to the date of last squid capture, November 16. The stippled area in this figure represents Verrill's conclusion on the growth rate of *L. pealei* off the "southern coast of New England." These reports do not agree in date, growth rate nor size distribution.

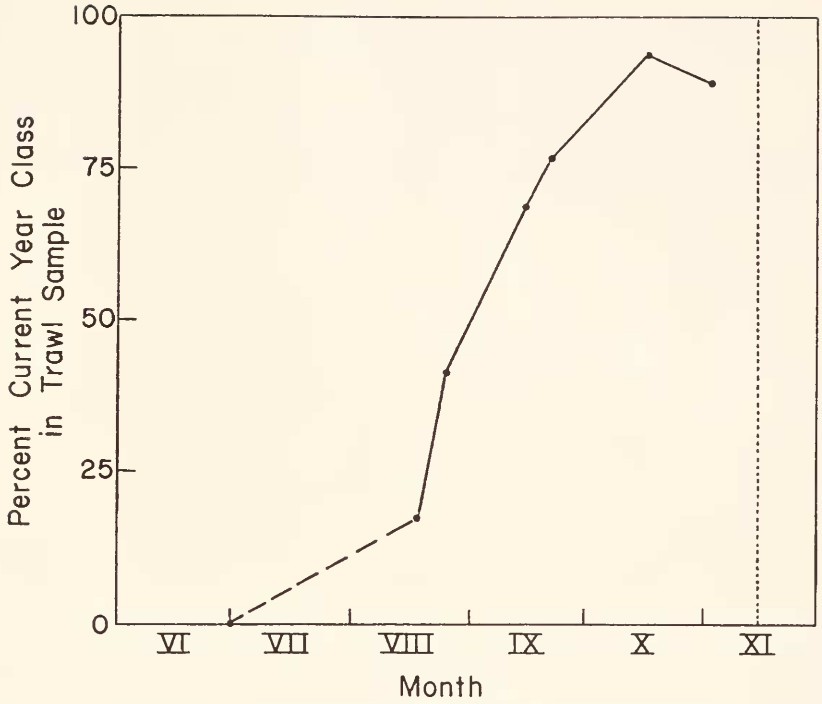

FIGURE 3. Percentage of current year class individuals in trawl samples for various dates. The dotted line on November 16 indicates the last date that *L. pealei* was captured in Menemsha Bight before its fall migration. A dashed line connects with data from a collection made with a shrimp trawl.

DISCUSSION

The accuracy of the foregoing estimates of growth rate and size distribution is dependent upon how well the measured samples represent the natural squid population. Owing to the mobility and seasonal migration of *L. pealei,* one can readily question the adequacy of daytime, otter trawl samples from a single depth zone and location. Furthermore, the size bias introduced through the collecting gear needs to be established in interpreting the results.

The consistency of the squid population in Menemsha Bight can only be implied by the regularity of sample size-frequencies and by comparison with other sources. The latter produced no significant differences when applied to records of miscellaneous collections on comparable dates in 1967 from Buzzards Bay, Vineyard Sound and Nantucket Sound, resulting from otter trawling, fishtrap hauls, squid jigging and fish stomach contents. Winter offshore collections of *L. pealei* show an increase in the numbers of individuals trawled in daylight hours and a positive correlation between depth and mean mantle length. This last factor may explain the size constancy of the one plus year class shown in Figure 2, by suggesting that this class may have been migrating through the sampling region during the study.

L. pealei does migrate vertically. For instance, newly hatched fry congregate near the surface in the best lit part of an aquarium and, during the warmer part of the year, adult squid are frequently seen swimming near the surface at night. The #35 otter trawl fishes in the first one to two meters above the bottom and it may well miss squid in upper strata. I suspect that the largest squid either swim high enough above the bottom to be missed by this net or are capable of avoiding

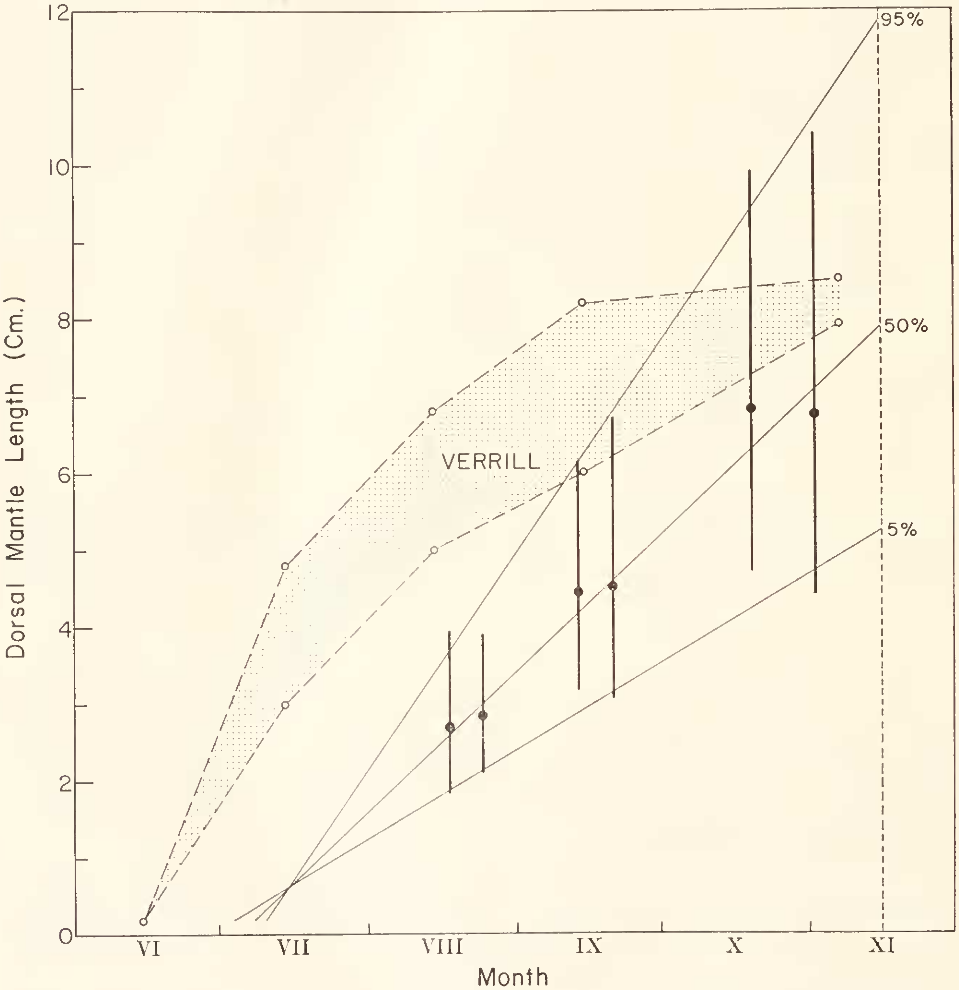

FIGURE 4. Two growth schemes for current year class *L. pealei*. The dorsal mantle length in centimeters is shown as a function of time. Verrill's data (1882) are indicated by a stippled envelope including the typical size range of his collections. The present study is represented by bars and dots showing the 5th, 50th and 95th percentile lognormal fit mantle lengths on six sampling dates. Linear regression lines are given for each of these percentile sizes. The dotted line on November 16 indicates the last date that *L. pealei* was captured in Menemsha Bight before the fall migration.

it, as the biggest individuals I have measured (including one male with a dorsal mantle length of 46.5 cm.) were taken in a fishtrap.

Selectivity

The selectivity of an otter trawl refers to the fact that it may retain individuals of different sizes with different efficiencies. Obviously, small individuals can slip through the net meshes and larger ones will be retained. Thus, selectivity is specified by the size *vs.* retention characteristics of a particular mesh size and species. This matter is discussed for several species of fish by Clark (1963).

Otter trawl selectivity can be estimated by comparing the catches of netting with different mesh sizes either on the same trawl or on similar nets fishing under comparable conditions. Such a comparison was made between the current year class *L. pealei* taken with the #35 net in Menemsha Bight on August 18 and two collections made by the Bureau of Commercial Fisheries R/V ALBATROSS IV which trawled in the same area at midday on August 17 and 18. The ALBATROSS IV used a #36 otter trawl with a $\frac{1}{2}$-inch mesh (1.5-cm.) stretched measure nylon liner in both the cod end and upper belly; it was 4 feet (1.2 m.) longer in each wing than the #35 net and more heavily protected for fishing on rough ground, but otherwise the nets were identical.

There were a total of 319 current year class individuals in these three collections, only 21 of which were caught in the #35 net. A comparison did not show a size bias in the #35 net sample and suggested that the entire size class straddled the transitional retention zones of the two trawl liners which had caused the #35 net to be uniformly less efficient in retaining this collection of squid. The 5th, 50th and 95th percentile lognormal fit mantle lengths for the ALBATROSS IV collections of August 17 and 18 and the A. E. VERRILL collection of August 18 were: 1.7, 2.2, 2.9; 1.9, 2.6, 3.4 and 1.9, 2.7, 4.0 cm., respectively.

The selectivity of the #35 net is probably the single most important factor in the explanation of the sample size class composition illustrated in Figure 3. As the current year class *L. pealei* grew, it was more efficiently retained by the net, and made up a larger proportion of the total catch. By assuming that the current year class made up 100% of the natural squid population and replotting Figure 3 on the basis of mantle length *vs.* per cent current year class in the samples, the 50% retention point for the #35 net was estimated to occur at a mantle length of 3.7 cm. This is consistent with the previous comparison and with Clark's data for fish.

Size distribution

Lognormal size-frequency distributions are not uncommon in juvenile animals and tend to occur in older animals where several age classes overlap in size and where mortality has reduced the abundance of the older classes. The mathematical philosophy of this distribution is contained in a monograph by Aitchison and Brown (1957); I will suggest some of the factors which may relate to the present case.

Net selectivity can cause the truncation of a size-frequency distribution if the smaller individuals are retained less efficiently than the larger ones. The A. E.

VERRILL collection of August 18 lay almost entirely below the 3.7 cm., 50% retention point, of the #35 net, and could be lognormally distributed as a result of net selectivity. Theoretically, the #36 net collections of the same and the previous day should have been influenced by a 50% retention point smaller than 3.7 cm. by the ratio of the liner mesh sizes (approximately 1.0 cm. mantle length when the twine diameters are taken into consideration). For practical purposes, the #36 net should not have shown a selectivity bias in the current year class collections of those dates. The size-frequencies of the ALBATROSS IV collections were strongly lognormal, indicating the condition of the natural population. This is borne out by the maintenance of lognormality in later collections and in older year classes.

A sexual dimorphism in the size-frequency relationship accompanies the onset of maturity in *L. pealei.* Haefner placed the inception of this dimorphism at a mantle length of 9.5 cm. and Verrill concluded that it took place at an age of eight months or a size of 6.2 to 18.8 cm. Thus, each of the older year classes shown in Figure 2 is a sum of two overlapping sex classes; the mature males generally larger than the females. The introduction of additional classes may help to explain the lognormality of the summed older year classes taken in contrast to the current year class. It was this contrast which made Cassie's method useful in the present study.

The relative abundance of the sexes did influence the size-frequencies of the samples. There were almost three times as many females as males in the one plus year class taken with a small trawl on June 30. This ratio was reduced to 2:1 on August 18 and remained approximately 1:1 thereafter. The two plus year class was composed mostly of mature males on August 25. Non-current year classes on October 20 and November 2 were poorly represented and scattered in size; as a result, their placement as two plus and one plus year classes, respectively, is tentative and based upon maturities. The current year class remained sexually immature throughout the sampling period, as did approximately one-half of the one plus year class. Spent females were rare in the collections.

Growth rates

The upper size limit in Verrill's growth scheme, as illustrated in Figure 4, was apparently constructed from the interface between mature and immature individuals listed in his tabulated results. It was his assumption that *L. pealei* matures in one year, an assumption that requires an individual to be a mature participant in 3 to 4 breeding migrations if it lives to that age. The size class separation shown in Figure 2 suggests that about half of the one plus year class does not mature short of the second fall migration. This, undoubtedly, explains part of the difference in growth schemes shown in Figure 4. It is instructive to note that the west coast species, *Loligo opalescens,* was reported to die shortly after breeding (McGowen, 1954; Fields, 1965; Hobson, 1965). Such mortality has not been demonstrated for *L. pealei,* but it is inconsistent with Verrill's growth scheme if it does occur.

As shown in Figure 4, the linear regression lines fit to the 5th, 50th and 95th percentile sizes intersect on July 16 close to the hatching size, 2 mm. mantle length (see Arnold, 1965). Without taking into account the changes in body proportions which occur soon after a squid hatches, one can use this extrapolation to suggest that the probable hatching date for the current year class squid used in this study was approximately July 9, 1967. If allowance is made for a relative increase in mantle length to total length soon after hatching, the probable hatching date would be a few days later. Surface water temperatures in Vineyard Sound ranged from 15 to 19° C. between mid-June and mid-July, 1967. A collection of freshly laid squid egg capsules taken in 14 m. of water northwest of Gay Head on September 19, 1967, hatched in 20 days in the laboratory at water temperatures of 16 to 18° C. Thus I estimate that the egg deposition which produced the current year class squid in this study took place about June 19, 1967.

TABLE I

Early growth rate of three loliginid squid

Species	Location	Month hatched	Growth rate, mm./month to given age	Reference
L. vulgaris	North Sea	VII	20 mm., 6 months*	Tinbergen and Verwey, 1945
L. vulgaris	Mediterranean Sea	VI or VII	16.3 mm., 3 or 4 months 13.6 mm., 5 or 6 months	Mangold-Wirz, 1963
L. opalescens	Monterey Bay, California	V	6 mm., 12 months	Fields, 1965
L. pealei	Vineyard Sound, Massachusetts	VI	30–48 mm., 1 month 25–34 mm., 2 months 20–27 mm., 3 months 16–17 mm., 4.75 months	Verrill, 1882
L. pealei	Menemsha Bight, Vineyard Sound, Massachusetts	VII	17.8 mm., 4 months†	Summers, this paper

* Tinbergen and Verwey reported ventral mantle lengths which are slightly shorter than the dorsal mantle lengths given by the other authors.

† This is the growth rate of the median, or 50th percentile size. The 5th and 95th percentile sizes have growth rates of 11.2 mm. and 27.5 mm. per month for the first four months, respectively. These three growth rates are illustrated by the linear regression lines in Figure 4.

Verrill gave the date of first significant hatching as "the second week in June." The difference between his date and the one given above may reflect a difference in years (1875 *vs.* 1967), different collecting sites, his acquaintance with Long Island Sound or a combination of these factors. Adult squid were abundant in Vineyard Sound by June 1, 1967, when several fishermen began catching them regularly. Sizable accumulations of squid egg capsules were taken in the Bureau of Commercial Fisheries fishtrap in Buzzards Bay on June 3 (Mr. C. L. Wheeler, personal communication) and from Falmouth Beach on June 17, 1967. Verrill's mid-June hatch seems distinctly early for the 1967 season.

I take these isolated collection of egg capsules and the narrowness of the current year class size distribution to be an indication that *L. pealei* breeding activity is highly localized and that the breeding season is made up of a number of these events. This is a logical consequence of Arnold's observation on the mating behavior of this species (1962), which indicated the importance of a visual stimulus in egg deposition.

The early growth rate of three loliginid squid is given in Table I. The first four entries are based upon modal analyses. With the exception of Fields' data, all of the entries are roughly comparable over the first few months of growth.

Summary

1. This paper reports estimates of the growth rate and size distribution of current year class *L. pealei* based upon the population statistics of daytime, otter trawl collections in Menemsha Bight during the second half of 1967.

2. The selectivity of a #35 otter trawl with a 1.25-inch mesh (3.2-cm.) stretched measure cod end liner was estimated by a 50% retention of *L. pealei* with a dorsal mantle length of approximately 3.7 cm.

3. The current year class, summed older year classes and individual older year classes of *L. pealei* were found to have lognormal size-frequency distributions.

4. The current year class could readily be separated from the older year classes by the use of Cassie's method on lognormal probability paper.

5. The growth rate of a median individual in the current year class of 1967 was found to be 1.8 cm. dorsal mantle length per month for the first four months past hatching.

6. Approximately one-half of the one-year-old *L. pealei* did not mature sexually before the second fall migration. None of the current year class *L. pealei* matured before the first fall migration.

7. The results indicate that *L. pealei* egg deposition is isolated in time and location, and repeated throughout the Vineyard Sound area from at least June through September.

LITERATURE CITED

Aitchison, J., and J. A. C. Brown, 1957. The Lognormal Distribution. Cambridge Univ. Press, London. 176 pp.

Arnold, J. M., 1962. Mating behavior and social structure in *Loligo pealii*. *Biol. Bull.*, **123**: 53–57.

Arnold, J. M., 1965. Normal embryonic stages of the squid, *Loligo pealii* (Lesueur). *Biol. Bull.*, **128**: 24–32.

Cassie, R. M., 1954. Some uses of probability paper in the analysis of size frequency distributions. *Austr. J. Mar. and Fr. Water Res.*, **5**: 513–522.

Cassie, R. M., 1962. Frequency distribution models in the ecology of plankton and other organisms. Contr. No. 111, New Zeal. Oceanogr. Inst. pp. 65–92. (also: Contr. No. 1169, WHOI Reprints.)

Clark, J. R., 1963. Size selection of fish by otter trawls, results of recent experiments in the northwest Atlantic. *ICNAF Spec. Publ.*, No. 5, 1963.

Fields, W. G., 1965. The structure, development, food relations, reproduction and life history of the squid *Loligo opalescens* (Berry). *Fish. Bull.*, California Fish and Game No. 131. 108 pp.

Haefner, P. A., Jr., 1964. Morphometry of the common Atlantic squid, *Loligo pealei*, and the brief squid, *Lolliguncula brevis* in Delaware Bay. *Chesapeake Sci.*, **5**: 138–144.

Hobson, E. S., 1965. Spawning in the Pacific Coast squid, *Loligo opalescens*. *Underwater Natur.*, **3**: 20–21.

Lesueur, C. A., 1821. Description of several new species of cuttlefish. *J. Acad. of Natur. Sci. Philadelphia,* **2**: 86–101.

Mangold-Wirz, K., 1963. Biologie de céphalopodes benthiques et nectoniques de la Mer Catalane. *Vie et Milieu, Suppl.,* **13**: 1–285.

McGowen, J. A., 1954. Observations of the sexual behavior and spawning of the squid, *Loligo opalescens,* at La Jolla, California. *California Fish and Game,* **40**: 47–54.

Summers, W. C., 1967. Winter distribution of *Loligo pealei* determined by exploratory trawling. *Biol. Bull.,* **133**: 489.

Sumner, F. B., R. C. Osburn and L. J. Cole, 1913. A biological survey of the waters of Woods Hole and vicinity. *Bull. Bur. of Fisheries,* **31** (1911). 2 vol.

Tinbergen, L., and J. Verwey, 1945. Zur Biologie von *Loligo vulgaris* Lam. *Arch. Néerl. Zool.,* **7**: 213–286.

Verrill, A. E., 1882. Report on the cephalopods of the northeastern coast of America. *Rep. U. S. Comm. Fisheries,* Part 7 for 1879: 211–455.